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FISHES AND DECAPODS OF SAN PABLO AND SUISUN BAYS

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INTRODUCTION

The distribution and abundance of the fishes in the 25-mile section of the Sacramento-San Joaquin River estuary, from San Pablo Bay to the Delta, varies greatly with the changing season and the accompanying changes in freshwater outflow and salinity.

During a 2-year survey of the area, 60 species of fish were recorded. Of these, 31 were typically saltwater forms, 5 were euryhaline but generally associated with the marine environment, 3 were euryhaline but generally associated with the freshwater environment, 13 were freshwater species, and 8 were anadromous.

Freshwater fishes were generally few in number and restricted to the upper end of the estuary. Marine fishes were generally restricted to the lower end of the estuary, and the abundance of several marine species fluctuated widely with season.

The middle portion of the area was characterized by the presence of anadromous and euryhaline species and seasonal immigrations and emigrations of marine and freshwater forms. There appeared to be few resident species.

Ocean salt moved farther upstream during the second year (1964) of the survey and the number of marine species increased. Some species taken in both years moved upstream earlier and farther in 1964 than in 1963.

The food habits of several species were investigated and although many organisms were utilized, one mysid shrimp, *Neomysis awatschensis*, formed an important and probably critical link in their food chain.

METHODS

The survey started in January 1963 and ended in December 1964.

Sampling in 15 to 40 feet of water was conducted from the 50-foot California Department of Fish and Game research vessel *Nautilus*. A 25-foot square-mouthed midwater trawl with a cod-end of ½-inch stretched mesh was towed at the surface, and an otter trawl with a 25-foot cork line and a cod-end of ¾-inch stretched mesh was towed on the bottom. Tows were usually 20 minutes long, and when possible were made alternately with and against the current. Because of variations in weather and tidal or river conditions, it was impossible always to follow the same procedures or sample with equal intensity from month to month (Table 1). During the first 6 months, while sampling and gear handling techniques were perfected, we did not survey the entire area. Routine coverage started in June 1963, and 1 week per month was devoted to the survey until December 1964.

TABLE 1

Number of 10-Minute Trawl Tows and Hours of Gill Net Fishing

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1963												
Pittsburg												
Midwater trawl	1.0	2.0	3.5	1.0	*	4.0	*	7.2	4.3	4.0	4.0	5.0
Otter trawl	*	*	2.0	1.0	*	6.0	*	5.8	4.0	5.0	4.0	4.0
Honker Bay												
Otter trawl	*	*	*	*	*	7.0	*	7.7	6.0	6.0	5.0	*
Gill net	*	*	*	*	*	50.1	*	4.0	4.0	5.0	4.0	3.0
Port Chicago												
Midwater trawl	*	*	*	*	*	4.0	*	3.0	*	2.0	4.0	8.0
Otter trawl	*	*	*	*	*	*	*	3.0	4.0	2.0	1.0	*
Grizzly Bay												
Otter trawl	*	*	*	*	*	2.0	*	8.8	3.0	6.0	*	*
Gill net	*	*	*	*	*	3.0	*	5.5	3.0	4.1	*	*
Martinez												
Midwater trawl	*	*	3.0	2.0	*	2.0	*	3.0	8.0	4.0	4.0	3.0
Otter trawl	*	*	*	2.0	*	2.0	*	10.0	3.0	6.0	6.0	3.4
West Suisun Bay												
Otter trawl	*	*	*	*	*	1.8	*	6.0	7.0	5.6	8.0	*
Gill net	*	*	*	*	*	1.2	*	4.5	3.5	4.8	7.0	3.5
East San Pablo Bay												
Midwater trawl	*	2.0	1.5	3.0	5.0	6.0	*	4.0	2.0	4.0	8.0	4.0
Otter trawl	*	4.5	5.0	2.0	1.0	12.4	*	2.0	1.0	3.0	6.0	2.0
East San Pablo Bay (Shallows)												
Otter trawl	*	7.0	5.0	*	*	*	*	1.0	6.0	8.0	7.0	*
Gill net	*	0.5	4.7	*	*	*	*	4.5	4.0	5.8	4.5	4.5
West San Pablo Bay												
Midwater trawl	*	5.0	6.0	5.0	36.6	12.0	*	11.0	11.0	8.0	3.5	4.0
Otter trawl	*	5.0	5.0	5.0	5.0	*	*	6.0	10.0	4.0	4.0	2.0
1964												
Pittsburg												
Midwater trawl	*	16.0	12.0	12.0	11.5	10.0	10.0	12.0	12.0	10.0	12.0	10.0
Otter trawl	*	14.2	11.0	12.0	11.0	11.5	11.0	9.5	12.0	12.0	6.0	10.0
Honker Bay												
Otter trawl	8.0	9.8	8.8	8.0	8.0	*	*	*	*	*	*	*
Gill net	5.0	5.0	5.0	5.0	5.0	*	*	*	*	*	*	*
Port Chicago												
Midwater trawl	*	5.5	17.7	12.0	18.5	6.0	6.0	4.0	8.0	6.0	4.0	4.0
Otter trawl	*	*	2.0	*	*	*	*	*	*	*	*	*
Grizzly Bay												
Otter trawl	8.0	10.0	8.0	12.0	10.0	*	*	*	*	*	*	*
Gill net	5.0	5.0	5.5	5.5	4.0	*	*	*	*	*	*	*
Martinez												
Midwater trawl	*	9.0	14.0	11.0	12.0	8.0	6.0	8.0	10.0	4.0	8.0	10.0
Otter trawl	*	5.3	12.0	11.5	7.5	10.0	8.0	6.0	4.0	6.0	6.0	8.0
West Suisun Bay												
Otter trawl	*	4.0	10.0	6.2	10.0	*	*	*	*	*	*	*
Gill net	*	5.0	4.5	4.0	4.0	*	*	*	*	*	*	*
East San Pablo Bay												
Midwater trawl	*	8.0	24.0	15.5	12.0	4.0	4.0	5.5	12.0	10.0	10.0	8.0
Otter trawl	*	8.4	8.0	6.0	16.0	9.0	10.0	11.0	12.0	12.0	8.0	8.0
East San Pablo Bay (Shallows)												
Otter trawl	8.0	10.0	10.0	5.1	12.0	*	*	*	*	*	*	*
Gill net	4.7	5.0	4.2	21.0	5.0	*	*	*	*	*	*	*
West San Pablo Bay												
Midwater trawl	*	4.0	*	*	*	3.1	1.0	*	*	*	*	*
Otter trawl	*	8.0	*	*	*	12.0	3.0	*	*	*	*	*

* Not surveyed.

Data describing the catch of the more important species were combined to show the monthly catch per 10 minutes of trawling with each net in five areas. The areas were 5 to 6 miles long. One area could usually be sampled in a day and each area, with the exception of west San Pablo Bay, contained a California Department of Water Resources chlorinity recording station. They were centered near the towns of Pittsburg, Port Chicago, Martinez, Crockett, and Pinole (Figure 1). Data from the two San Pablo Bay areas were usually combined, as were the data from Port Chicago and Martinez.

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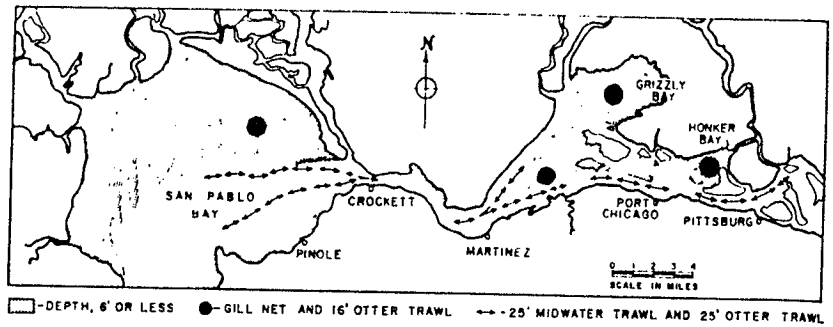

FIGURE 1. Location of sampling areas.

Midwater trawl tows were made outside the ship channel marker buoys. Otter trawl tows were made outside the marker buoys where level, obstruction-free bottom was known to exist. Such bottom conditions were not common in the deep-water portions of Suisun Bay, but it was possible to find favorable otter trawling conditions in most of San Pablo Bay in water 15 to 40 feet deep.

The extensive shallow areas in Honker Bay, Grizzly Bay, western Suisun Bay, and northeastern San Pablo Bay were sampled from a 19-foot launch with an otter trawl and a gill net (Figure 1). The gill net was 450 feet long, 12 feet deep, and had nine, 50-foot sections of different sized (2½- to 7-inch stretched) mesh. The gill net was usually set in early or midmorning and recovered in early or midafternoon. The otter trawl had a 16-foot cork line, and a ½-inch stretched mesh cod-end and was towed for 10 or 20 minutes. Sampling with the 16-foot otter trawl and gill net started routinely in June 1963 and was stopped in May 1964 (Table 1). Data describing the catch of the more important species were combined to show the monthly catch per 10-minute tow and per 1 hour of gill netting.

In the field, specimens were identified, counted or numbers estimated, and the stomach contents of the more important or abundant species were examined. Stomach samples were not measured volumetrically.

RESULTS

The following discussion of the occurrence and distribution of the animals taken during the survey is, in some cases, based on my impressions and observations. Some of the animals were not vulnerable to our gear and were taken incidentally or in small quantities. Some were quite susceptible to the nets at one size but not at another, so accurate quantitative comparisons were not possible.

The animals are listed in systematic order, and alphabetically by common name within major groups. Following the name of each species, a short summary including the habitat it is usually associated with, total number caught, gear with which the animal was caught, area, date, and size range is given. The more abundant or economically important species are dealt with in more detail, and where appropriate, more data are presented.

Invertebrates

Colonial hydroid, Hydrozoa. Freshwater.

Taken incidentally by otter trawl throughout Suisun Bay, never in San Pablo Bay. Not identified, but presumed to be *Cordylophora lacustris* which is known to be in the lower Delta (Aldrich, 1961).

Small jellyfish, Scyphozoa. Marine.

Incidentally in midwater trawl in San Pablo Bay year-round; a few from Martinez to Pittsburg in spring, summer, and fall.

Comb jelly, Ctenophora. Marine.

About 200. San Pablo Bay, April 1964.

Bay snail, *Nassarius obsoletus*. Marine.

Common, often abundant in San Pablo Bay, but rare east of Carquinez Strait.

Asiatic clam, *Corbicula fluminea*. Freshwater. Introduced.

Occasionally at Pittsburg, Honker Bay, Martinez.

This clam is abundant in the freshwater portion of the Sacramento-San Joaquin Delta, where at times, it forms large beds and becomes a problem in irrigation and drainage works.

Basket cockle, *Clinocardium nuttalli*. Marine.

Occasionally, San Pablo Bay.

Bent-nose clam, *Macoma nasuta*. Marine.

Occasionally, San Pablo Bay.

Mud clam, *Macoma inconspicua*. Marine.

Occasionally, San Pablo Bay.

Japanese littleneck, *Tapes semidecussata*. Marine. Introduced.

Occasionally, San Pablo Bay.

Mussel, *Modiolus* sp. Marine.

Occasionally, San Pablo Bay.

Native oyster, *Ostrea lurida*. Marine.

Occasionally, San Pablo Bay.

Soft-shell clam, *Mya arenaria*. Marine. Introduced.

Occasionally, San Pablo Bay.

Isopod, *Synidotea laticauda*. Marine.

A few at Pittsburg and Crockett, but most abundant at Port Chicago and Martinez in spring and summer of 1964.

Opossum shrimp, *Neomysis awatschensis*. Euryhaline.

This mysid, although too small to be properly sampled by our nets, was at times so abundant that thousands were retained in the webbing mixed in with the catches of the midwater trawl. Heavy concentrations were observed off Martinez in March 1963 and off Pittsburg, Port Chicago, and Martinez in April and May 1964. Lesser numbers were taken at Crockett during March 1963 and May 1964.

Oriental shrimp, *Paleomon macrodactylus*. Euryhaline. Introduced.

No one knows when or by whom this shrimp was introduced into California. Although never common, it was taken most often in Suisun Bay during April, September, and October and in San Pablo Bay

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during March and April. Many more were taken in Suisun Bay than in San Pablo Bay. In the spring, small shrimp predominated. In the fall, larger individuals and some egg-carrying females were observed.

Bay shrimp, Crago. Marine-Euryhaline.

Bay shrimp, at one time, supported a large commercial fishery in San Francisco Bay. Two species, *Crago franciscorum*, and *Crago nigracauda*, made up almost all of the commercial catch. A third species, *Crago nigromaculata*, was of little importance to the fishery (Bonnot, 1931; Skinner, 1962).

Israel (1936) studied the life histories of the three species from June 1931 to June 1933. He found that *C. franciscorum* was the most tolerant of fresh water and was found 70 miles from the Golden Gate in the San Joaquin River. He also found that both *C. franciscorum* and *C. nigracauda* moved toward the ocean as the spawning season approached and the eggs hatched in water of high salinity. Both species reproduced at the end of their first year, *C. franciscorum* from December to June, and *C. nigracauda* from April to September. Young shrimp were found at some distance from the ocean in water of reduced salinity.

Our nets caught *C. franciscorum* almost exclusively. *C. nigracauda* was caught in small numbers only during May and June 1964 in San Pablo Bay. *C. nigromaculata* was never knowingly taken.

We caught no bay shrimp above Carquinez Strait from February through April 1963, and only relatively small numbers in San Pablo Bay (Figure 2). From August through December 1963, shrimp were present throughout the survey area. Abundance was lowest off Pittsburg.

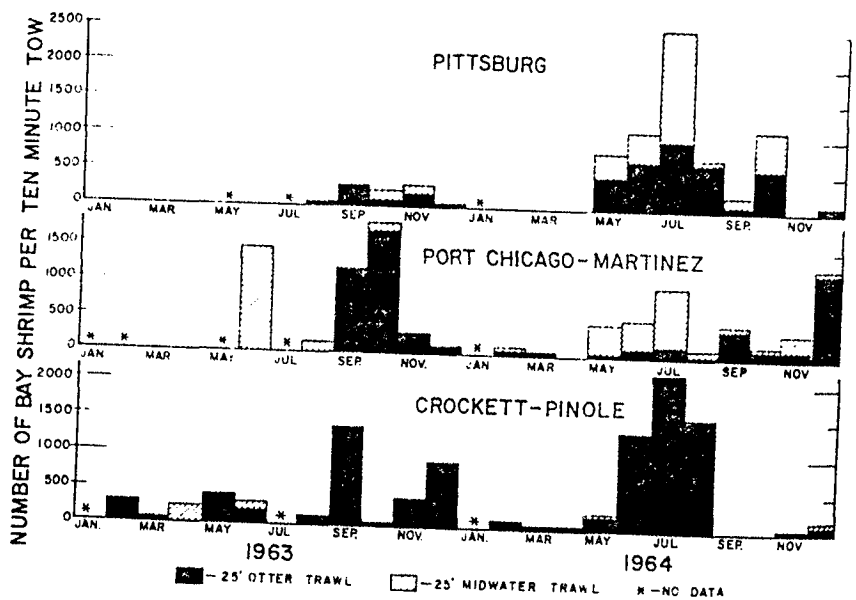

FIGURE 2. Monthly trawl catch of bay shrimp, *Crago*.

A few bay shrimp remained in San Pablo Bay and western Suisun Bay from February to May 1964. We caught none off Pittsburg during that period.

In contrast to the summer of 1963, *C. franciscorum* was abundant off Pittsburg during the summer of 1964. Catches were somewhat smaller than in 1963 at Martinez and Port Chicago.

From September to December 1964, shrimp all but disappeared from San Pablo Bay. Although catches were variable in Suisun Bay, shrimp remained there until the end of the survey.

We kept no record of the size composition of the catch. But it is my opinion that small shrimp were more common in Suisun Bay than in San Pablo Bay.

Market crab, Cancer magister. Marine.

From July to December 1963, 33 small (4 to 10 cm) *C. magister* were caught in the San Pablo Bay otter trawl. Between May and December of 1964, over 2,000, in the same size range, were caught in the same area. At times they were taken at a rate of more than 200 per 10-minute tow.

No crabs were taken above Carquinez Strait in 1963 but 56 individuals 4 to 14 cm wide were caught near Martinez from July to December 1964.

Ascidian, Molgula verrucifera. Marine.

At times *M. verrucifera* was so abundant in San Pablo Bay bottom tows that it was impossible to haul the trawl aboard by hand. We never found it east of Crockett.

FISHES

Pacific lamprey, Entosphenus tridentatus. Anadromous.

Total—3. Midwater trawl. Martinez: April 1964; 66 cm.

San Pablo Bay: May 1963; 59 to 64 cm.

The Pacific lamprey is found in nearly all California streams which enter the ocean, unless blocked by barriers or low flows. Adults often start their spawning migration into fresh water in the fall and in some rivers these migrations continue into the spring, when masses of lampreys are seen ascending obstructions and fish ladders (Kimsey and Fisk, 1964).

After spending 3 or 4 years in their natal stream, young Pacific lampreys, when about 15 cm long, migrate to sea.

The Pacific lamprey parasitizes other fishes, but apparently without the disastrous result attributed to the sea lamprey of the Atlantic.

Unidentified lamprey. Anadromous.

Total—6. Midwater trawl. Suisun Bay: November 1963–May 1964; 11 to 18 cm. San Pablo Bay: October 1963–May 1964; 15 to 18 cm.

These were either downstream migrant Pacific lampreys or river lampreys, *Lampetra ayresi*. Little is known about the habits and behavior of the river lamprey, but it is found in central California streams and is probably responsible for most of the attacks on fish in California streams (Kimsey and Fisk, 1964).

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Brown smoothhound, *Triakis henlei*. Marine.

Total—42. Otter trawl. San Pablo Bay.

This shark was taken from late spring to late summer in both years. About 60 percent of those taken were 22 to 35 cm long and 40 percent were 40 to 69 cm long.

One individual containing identifiable food had been eating *Crago franciscorum*.

Dogfish, *Squalus acanthias*. Marine.

Total—4. Gill net. San Pablo Bay: April 1964. Females, 75 to 87 cm long, all containing well developed embryos.

Big skate, *Raja binoculata*. Marine.

Total—47. Otter trawl. San Pablo Bay.

Skates were caught in September and November 1963 and February, March, May, June, October, and December 1964. Over 70 percent were 10 to 20 cm wide, and the rest were from 25 to 60 cm.

Bat ray, *Myliobatis californicus*. Marine.

Total—1. Otter trawl. San Pablo Bay: July 1964; 70 cm wide.

Green sturgeon, *Acipenser medirostris*. Anadromous.

Total—34. Gill net, otter trawl. Suisun Bay, San Pablo Bay.

Almost nothing is known about the life history and behavior of the green sturgeon in California.

The greatest gill net catch was recorded in September, in San Pablo Bay. Otter trawl tows showed no particular pattern of distribution or abundance. However, in Suisun Bay, 67 percent of the green sturgeon were 27 to 35 cm long, and 33 percent were 40 to 48 cm long, while in San Pablo Bay, 1 fish (5 percent) was 25 cm long and 95 percent were between 40 and 74 cm long.

Five sturgeon stomachs collected in Suisun Bay contained identifiable material, which included: *Corophium* sp., annelid worms, *Crago franciscorum*, and *Neomysis awatchensis*.

Eight stomachs from San Pablo Bay contained: *Crago franciscorum*, *Macoma* sp., the amphipod *Photis californica*, *Corophium* sp., *Synidotea laticauda*, unindentified crab, and fish.

White sturgeon, *Acipenser transmontanus*. Anadromous.

Total—146. Gill net, otter trawl. Suisun Bay, San Pablo Bay.

The white sturgeon was once fished commercially in the estuary but has been protected since 1917. A minor but growing sport fishery exists with most catches recorded in late summer and fall in San Pablo Bay (Skinner, 1962). The results of a tagging program conducted in 1954–55 suggest a winter or spring upstream migration and a summer downstream migration of large white sturgeon in the estuary (Pycha, 1956).

We took the greatest number of large white sturgeon in San Pablo Bay in October and November 1963. Sturgeon were common enough at that time that several were taken in the 16-foot otter trawl. Although catches were never large in Suisun Bay, gill netting was most successful there in April, May, and June.

In Suisun Bay, 71 percent of the fish were between 23 and 35 cm long and 29 percent were 40 to 90 cm long. In San Pablo Bay, 3 percent were between 23 and 35 cm, and 97 percent were from 60 to 120 cm long.

Thirty-nine white sturgeon stomachs collected from Suisun Bay contained identifiable food. In order of their frequency of occurrence, the following organisms were found: *Neomysis awatschensis*, *Corophium* sp., *Crago franciscorum*, *Palcmon macrodactylus*, *Synidotea laticauda*, clam remains, and annelid worms.

In San Pablo Bay, 25 stomachs contained identifiable food. It included clams (mostly *Macoma* sp.), annelid worms, *Synidotea laticauda*, *Crago franciscorum*, fish eggs, *Corophium* sp., *Photis californica* and unidentifiable crab.

American shad, *Alosa sapidissima*. Anadromous. Introduced.

Total—about 6,200. Gill net 188, midwater trawl 5,872, otter trawl 200. Suisun Bay, San Pablo Bay.

American shad were introduced into California in 1871. Within a few years a commercial gill net fishery had developed and the fish were so abundant that they were considered a nuisance. The estuary was closed to commercial fishing in 1957 (Skinner, 1962).

Shad spend most of their life at sea and little is known of their movements there. Adults enter the estuary in early spring and proceed upstream to spawn in fresh water. Skinner (1955) analyzed the commercial shad fishing records for the 9-year period of 1946–1954. He found that 88 percent of the shad caught between Martinez and Pittsburg were landed during the 7-week period from April 10 to May 29.

Ripe or ripening adult shad were taken in our gill nets from February through June. An occasional adult was caught by midwater trawl during the same months. In Grizzly Bay in September 1963, 4 adults with "spent" gonads were caught. No one knows how many if any shad in California survive spawning and return to the ocean. This fall catch of spent shad suggests that some do.

We examined 72 adult shad stomachs which contained identifiable food. They held, in order of the frequency of occurrence, *Neomysis awatschensis*, copepods, *Crago franciscorum*, larval fish, and *Corophium* sp. Hatton (1940) found after examining 109 adult shad stomachs from fish taken in Suisun Bay that two-thirds of them contained *Neomysis awatschensis* and one-third copepods.

Shad spawn upstream from our survey area. Hatton (1940) observed spawning shad in the upper Delta and the streams flowing into it. He reported spawning along the entire length of the Sacramento River and far upstream in some of its tributaries. Hatton believed that even though shad did move into the San Joaquin River, it was not used extensively as a spawning area.

The results of studies by the California Department of Fish and Game as well as the consensus among residents of the area indicates that most spawning now takes place in the Sacramento River and its tributaries above the Delta.

In California, shad spawn in the spring and summer. Eggs or small larvae have been found in the Delta as early as April and as late as October Erkkila *et al.*, 1950; Chadwick, 1958). Hatton (1940) first collected young shad at his Martinez station on May 4, 1939. He further reported that the "migration" continued until January 1940.

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At Pittsburg, we first took young of the 1963 year-class in August of that year (Figure 3). A peak was reached in November, and following a decline in December, catches of small shad were low until August 1964 when young of the 1964 year-class were caught. While apparently not as abundant at Pittsburg as the 1963 year-class, the 1964 year-class was taken in moderate numbers until the end of our survey.

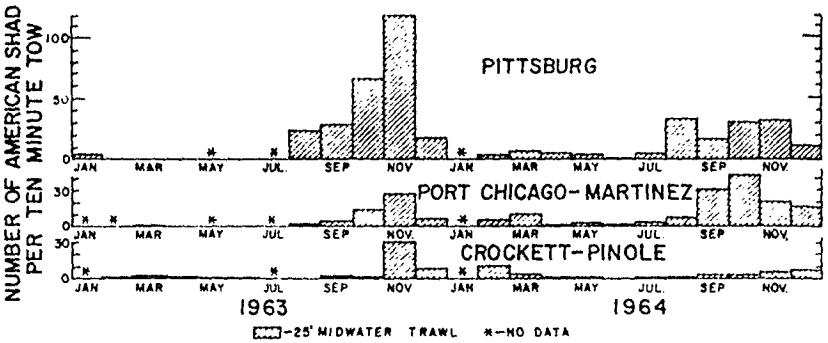

FIGURE 3. Monthly trawl catch of young-of-the-year American shad, *Alosa sapidissima*.

At Port Chicago and Martinez almost no small shad were caught until August and September 1963. The 1963 year-class reached a low peak of abundance in November. After that, catches were generally low until July 1964, when the 1964 year-class appeared. That year-class reached a peak in November and was commonly taken in December.

In San Pablo Bay, low numbers of the 1962 year-class (6 to 12 months old) were taken from February through June 1963 (Figure 3). In September, a few 1963 year-class shad appeared and a low peak was reached in November. Some small shad were caught in San Pablo Bay until the end of the survey, but only a few 1964 year-class fish were found.

Identifiable food was found in 59 young-of-the-year shad. Food items, in the order of their occurrence, were: *Neomysis awatschensis*, copepods, larval fish, and *Corophium* sp.

Many of the trawl tows, in addition to young-of-the-year shad, yielded a few larger fish that were in their second year of life. Although no accurate record of the occurrence of these yearlings was kept, they were recorded from all areas and at times made up as much as 10 percent of the catch.

Nine yearlings contained identifiable food which consisted of *Neomysis awatschensis* and copepods.

Pacific herring, *Clupea pallasi*. Marine.

Total—about 100,000. Midwater trawl, Suisun Bay, San Pablo Bay.

Adult herring enter San Francisco Bay in the winter and spring, spawn, and return to the sea immediately. Most spawning takes place in San Francisco Bay near Tiburon and Sausalito. However, during past dry periods spawning has been reported in San Pablo Bay and Carquinez Strait. It is generally believed that reduced salinity limits upstream spawning (Miller and Schmidtke, 1956).

In San Pablo Bay, we caught small numbers (less than one fish per tow) of ripe or ripening adult herring in February 1963. No adults were found at Pittsburg that year but occasionally they were taken near Martinez. Newly-hatched herring appeared in San Pablo Bay in February and March 1963 (Figure 4). They increased in number to a peak of several hundred per tow in May and June. A few were caught in August and young-of-the-year were almost totally absent from September 1963 on. A few (less than one per tow) young of the 1963 year-class were taken near Martinez and Port Chicago in June and August 1963.

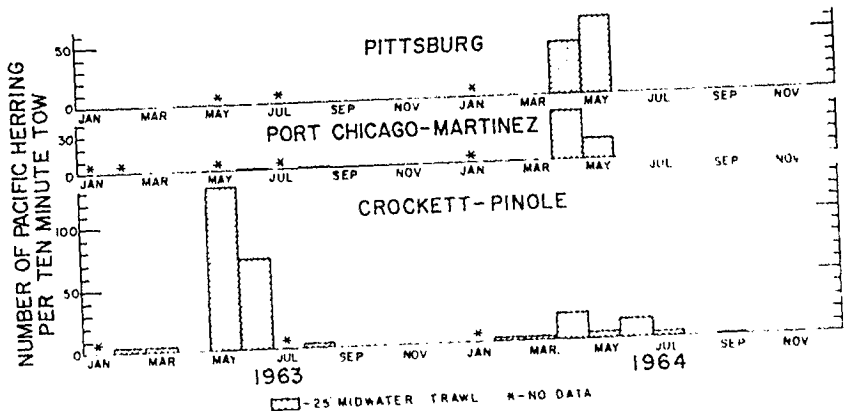

FIGURE 4. Monthly trawl catch of young-of-the-year Pacific herring, *Clupea pallasi*.

Unlike 1963, when almost no young herring were found east of Carquinez Strait, many were caught in 1964, throughout Suisun Bay. These fish were 3 to 6 cm long and were most abundant in the upstream areas off Pittsburg and Port Chicago. They were caught during April and May 1964 and then abruptly disappeared.

In 1964, adult herring, although few in number, were caught during January, February, and March in San Pablo Bay. Young of the 1964 spawning appeared in San Pablo Bay in April, May, and June but were not as plentiful as the 1963 year-class (Figure 4).

Threadfin shad, *Dorosoma petenense*. Fresh water—Euryhaline. Introduced.

Total—2,050. Midwater trawl. Suisun Bay, San Pablo Bay.

The threadfin shad was introduced into California, from Tennessee, in 1953. It is present in many central California reservoirs and has, in recent years, become established in the Sacramento-San Joaquin Delta. It has become an important food of larger fishes in many areas. The threadfin shad spawns at intervals after the water temperature reaches

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about 21° C. and ceases in the fall when the temperature drops below this (Kimsey and Fisk, 1964).

During September, October, and November of 1963 and 1964, threadfin shad were commonly caught off Pittsburg and Port Chicago. Peak catches of from 50 to 80 fish per tow were reached in November. Smaller catches were made off Martinez during the same months.

No threadfin shad were found in San Pablo Bay until November and December of 1963, when 3 to 5 fish per tow were caught. In November and December of 1964, threadfin shad were again caught at low rates.

Northern anchovy, *Engraulis mordax*. Marine.

Total—about 120,000. Midwater trawl.

Anchovies enter San Francisco Bay in spring and summer, but little is known about the amount of spawning that takes place in the bay. World wide, anchovies spawn over a broad range of conditions from oceanic to estuarine.

A smaller "brackish water" subspecies of *E. mordax* was reported in San Francisco Bay (Roedel, 1953), but we made no attempt to identify or separate it.

In late spring and summer of both 1963 and 1964, many anchovies entered San Pablo Bay (Figure 5). All ages, including many ripe and ripening adults up to 17 cm in length, were caught. As summer progressed, the proportion of large fish decreased until, in the fall and early winter, only recently-born and some 1- or 2-year-old fish were found.

Fewer anchovies were caught above Carquinez Strait but the proportion of young to adults was about the same as in San Pablo Bay. No anchovies were taken in the Pittsburg area until August 1964.

Only seven anchovies containing identifiable food were examined. All had been feeding on the copepod *Acartia clausi*.

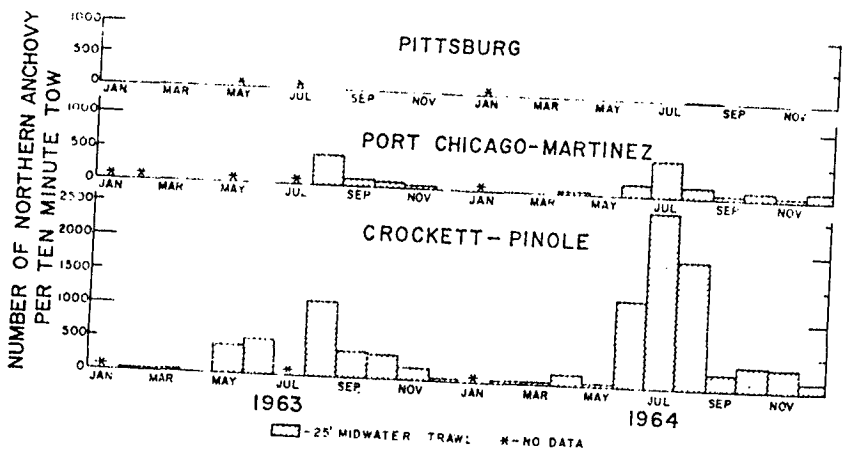

FIGURE 5. Monthly trawl catch of northern anchovy, *Engraulis mordax*.

King salmon, *Oncorhynchus tshawytscha*. Anadromous.

Total—682. Gill net, midwater trawl. Suisun Bay, San Pablo Bay.

The Sacramento-San Joaquin River run of king salmon is one of the largest on the Pacific Coast. In the past 15 years, estimates of spawning adults have ranged from 100,000 to 500,000 annually. Most mature fish move upstream in the fall, but there is a smaller spring run and a still smaller winter run (Fry, 1961; Skinner, 1962). Some mature king salmon are probably in the estuary during all months of the year.

The general movement of upstream migrant salmon in the estuary is well understood. We made no special effort to catch them and our nets were not designed or set to do so. During the survey, we caught only 20 adult or precocious male king salmon, all in Suisun Bay. Most (18) were fall-run fish and were taken between August and November. One was caught in May and one in June.

It is generally accepted that mature salmon do not feed while in fresh water. The stomachs of all those we caught were empty.

Young salmon move downstream soon after they emerge from the gravel. In the past, the peak of the downstream migration has been observed from February to April (Rutter, 1903; Hatton, 1940; Erkkila *et al.*, 1950).

Downstream migrants were present in almost all months and apparent peaks of abundance were reached during April, May, or June and November (Figure 6). In the spring, these young fish were from 6 to 10 cm long while in the fall, they were 10 to 17 cm long.

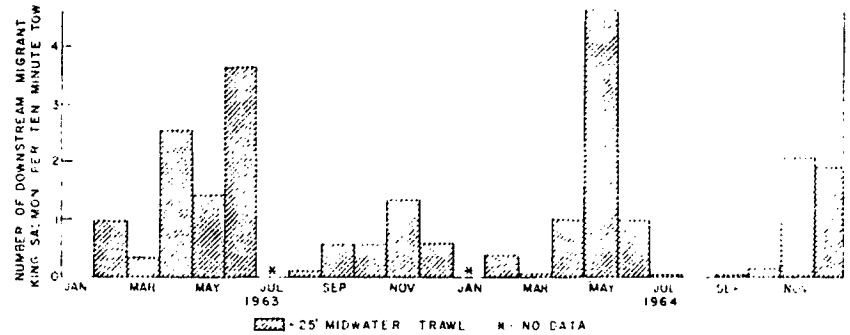

FIGURE 6. Monthly trawl catch of downstream migrant young-of-the year king salmon, *Oncorhynchus tshawytscha*.

In Suisun Bay, the stomachs of 37 small (7 to 15 cm) salmon held identifiable food. Terrestrial insects and spiders were present in 32, *Neomysis awatschensis* in 14, *Synidotea laticauda* in 1, and *Corophium* sp. in 1.

In San Pablo Bay, 25 downstream migrants contained identifiable food. Of these, 17 had been eating terrestrial insects or spiders. *Neomysis awatschensis* was found in 5, "fish" in 4, and *Crago franciscorum* in 1.

Rutter (1903) and N. B. Scofield (1913) found insects to be the most important food item in the diet of downstream migrant king salmon.

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Steelhead rainbow trout, *Salmo gairdneri*. Andromous.

Total--26. Gill net, midwater trawl. Suisun Bay.

After hatching, steelhead trout remain in fresh water for 2 or more years. Little is known of their habits in the ocean. In a large river such as the Sacramento, upstream and downstream migrants are present at all times but the bulk of the spawning fish move upstream in the winter and spring (Shapovalov and Taft, 1954).

We caught steelhead in every month but June, July, November, and December. Their size ranged from 24 to 64 cm.

Only two steelhead containing identifiable food were examined, each had been eating insects and *Synidotea laticauda*.

Night smelt, *Spirinchus starksi*. Marine.

Total—7. Midwater trawl. San Pablo Bay. February–March 1963.

Pond smelt, *Hypomesus transpacificus*. Fresh water—Euryhaline.

Total—about 7,100. Midwater trawl. Suisun Bay, San Pablo Bay.

Almost all pond smelt were found in Suisun Bay (Figure 7). Highest catches were made in summer and fall at Pittsburg. Small fish, 2 to 5 cm long, appeared in June and July and very few individuals greater than 8 or 9 cm were ever caught.

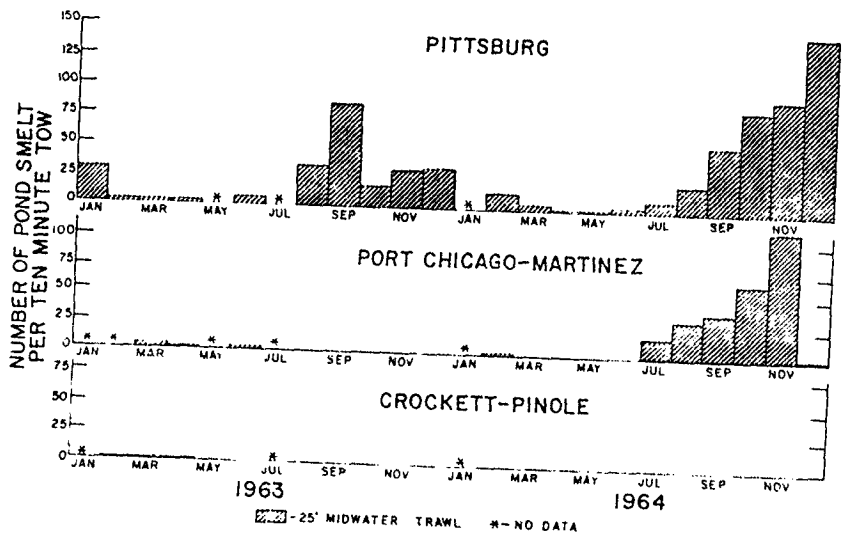

FIGURE 7. Monthly trawl catch of pond smelt, *Hypomesus transpacificus*.

Sacramento smelt, *Spirinchus thaleichthys*. Marine-Euryhaline.

Total—at least 20,000. Midwater trawl, otter trawl. Suisun Bay, San Pablo Bay.

Ripening adults (8–10 cm) were found in San Pablo Bay and western Suisun Bay in March and April 1963 (Figure 8). In May, a large number of 2 to 6 cm smelt appeared in the Crockett-Pinole area. It was not possible to count or estimate the catch reliably at this time because many of the small fish were not retained in our nets.

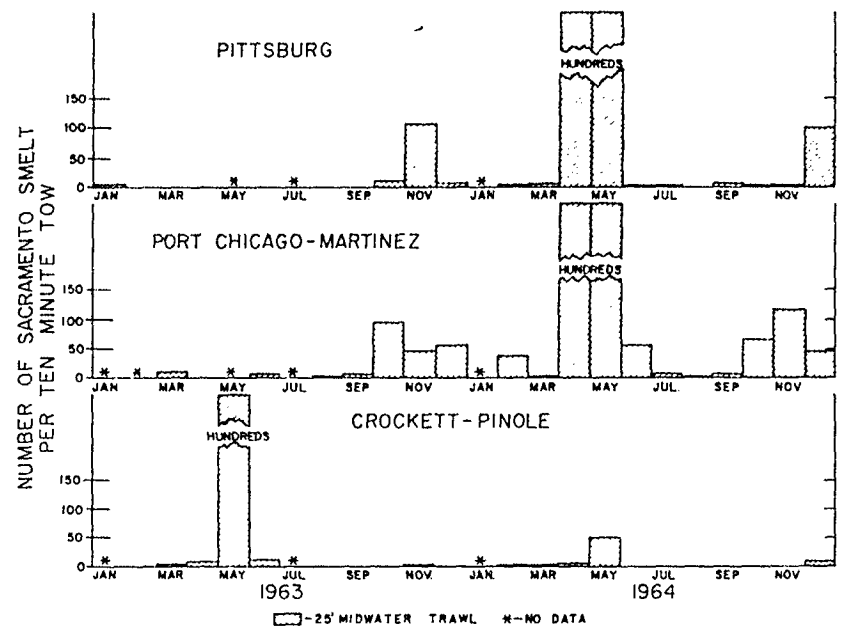

FIGURE 8. Monthly trawl catch of Sacramento smelt, *Spirinchus thaleichthys*.

By August 1963 almost all Sacramento smelt had disappeared from San Pablo Bay. They were caught in Suisun Bay where they remained through the winter.

Small *S. thaleichthys*, 2 to 6 cm long, were abundant off Pittsburg, Port Chicago, and Martinez during April and May 1964, but were relatively uncommon in San Pablo Bay. Again, many of the fish passed through our nets and reliable counts were not possible. After a summer decrease, catches increased in October, November, and December. At that time, two sizes of smelt were in evidence; one group at 6 to 8 cm, and another of ripening adults at 10 to 13 cm.

Surf smelt, *Hypomesus pretiosus*. Marine.

Total—8. Midwater trawl. Suisun Bay: March–April 1964, 12 to 19 cm. San Pablo Bay: March 1963, 8 cm; February–March 1964, 8 to 12 cm.

Whitebait, *Allosmerus elongatus*. Marine.

Total--2. Midwater trawl. San Pablo Bay: May 1963, 12 cm; February 1964, 7 cm.

Carp, *Cyprinus carpio*. Fresh water. Introduced.

Total—458. Gill net, midwater trawl, otter trawl. Suisun Bay.

The largest catches of carp were made in the shallows of Honker and Grizzly Bays during spring months. However, one otter trawl tow off Port Chicago in September 1963 yielded 25 large carp.

Goldfish, *Carassius auratus*. Fresh water. Introduced.

Total—1. Gill net. Honker Bay: November 1963, 20 cm.

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Sacramento blackfish, *Orthodon microlepidotus*. Fresh water.

Total—4. Gill net, otter trawl. Honker Bay, Grizzly Bay, Martinez: March, April 1963 and 1964, 25 to 42 cm.

Sacramento squawfish, *Ptychocheilus grandis*. Fresh water.

Total—6. Gill net, midwater trawl. Pittsburg, Honker Bay, Grizzly Bay: June, September 1963, February 1964, 39 to 52 cm.

One squawfish with identifiable food had been eating small striped bass.

Splittail, *Pogonichthys macrolepidotus*. Fresh water.

Total—291. Gill net, midwater trawl, otter trawl. Suisun Bay, San Pablo Bay.

Splittail were distributed much the same as carp. Highest catches were made in Honker and Grizzly Bays, but two fish were caught in San Pablo Bay. Two size groups, one between 10 and 15 cm and one with a mean length of 25 cm, were about equally represented.

Sacramento western sucker, *Catostomus occidentalis*. Fresh water.

Total—3. Gill net, otter trawl. Honker Bay: June, October 1963, February 1964, 39 to 47 cm.

Black bullhead, *Ictalurus melas*. Fresh water. Introduced.

Total—1. Gill net. Honker Bay: February 1964, 29 cm.

Brown bullhead, *Ictalurus nebulosus*. Fresh water. Introduced.

Total—1. Otter trawl. Grizzly Bay: March 1964, 15 cm.

White catfish, *Ictalurus catus*. Fresh water. Introduced.

Total—53. Gill net, midwater trawl, otter trawl. Suisun Bay.

White catfish were found all over Suisun Bay, with the best catches recorded in Honker Bay. Most were between 20 and 40 cm long but a few as small as 15 cm long were taken.

We examined the stomachs of 28 white catfish containing identifiable food. *Neomysis awatschensis* was found in 24, *Corophium* sp. in 14, *Crago franciscorum* in 6, and *Palaemon macrodactylus*, annelid, clam and fish in each.

Pacific tomcod, *Microgadus proximus*. Marine.

Total—259. Midwater trawl, otter trawl. Suisun Bay, San Pablo Bay.

Over 80 percent of the tomcod were taken in San Pablo Bay. All but one (caught at Port Chicago) of the remainder were found near Martinez. The fish ranged from 7 to 23 cm in length. No particular pattern of seasonal distribution or abundance was apparent.

Only one specimen containing food was examined; it had been feeding on *Crago franciscorum*.

Threespine stickleback, *Gasterosteus aculeatus*. Fresh water—Euryhaline.

Total—11. Midwater trawl, otter trawl. Suisun Bay, San Pablo Bay: March, May, August 1963, April, May, July 1964, 2 to 3 cm.

Bay pipefish, *Syngnathus griseolineatus*. Marine.

Total—2. Midwater trawl. San Pablo Bay: March 1963, February 1964, 20 to 23 cm.

Striped Bass, *Roccus saxatilis*. Anadromous. Introduced.

Total—About 16,000. Gill net, midwater trawl, otter trawl. Suisun Bay, San Pablo Bay.

Striped bass were introduced into California in 1879. They soon became established in the Sacramento-San Joaquin River system, and in a few years supported large commercial and sport fisheries (Skinner, 1962). Commercial fishing was outlawed in 1935, but the sport fishery is still the most important in the area.

Striped bass are migratory fish. As they pass through various stages of their life history, they travel to different areas within the Sacramento-San Joaquin River system.

Calhoun (1952), after analyzing the results of tagging studies conducted in 1947, 1950, and 1951, felt that in the summer months, adult bass are distributed mainly in San Francisco Bay and the ocean. In the fall and winter most of them move upstream to San Pablo Bay, Suisun Bay, and the Delta. In the spring the spawning population moves farther upstream where they spawn, mostly during May and June, in fresh water of 15°C or higher. After spawning, most large fish return to the lower bays and the ocean (Calhoun, 1952).

We did not feel that our gear sampled the adult population adequately. However, our limited catches did indicate that large bass were generally most abundant in Suisun Bay in the summer and fall and in San Pablo Bay in the fall and winter (Figure 9). The large catch of February 1963 was based on a ½-hour experimental gill net set.

Striped bass eggs are free-floating and hatch in 2 or 3 days. The larvae are feeble swimmers and for 1 or 2 weeks are at the mercy of the current. In the Sacramento-San Joaquin River system they are carried downstream to the Delta and upper bays at a rate depending on the magnitude of river outflow (Calhoun and Woodhull, 1948; Erkkila *et al.*, 1950). Scofield and Bryant (1926) reported that young bass were plentiful in San Francisco Bay and the upper bays until the cold of winter set in. They believed that at this time a seaward migration took place.

Our survey started when the 1962 year-class of striped bass was 7 to 9 months old. That year-class was rare in Suisun Bay but relatively common in the San Pablo Bay channel in the winter and spring of 1963 (Figure 10).

Young of the 1963 year-class were first caught off Pittsburg and in Honker and Grizzly Bays during August 1963. Catches reached a peak in Honker and Grizzly Bays in September and started to decline in October. Only a few fish were caught in January 1964. In deeper water off Pittsburg, concentrations were high from September, when most fish were caught in the otter trawl, to November, when most fish were caught in the midwater trawl. A decline took place in December. Concentrations in all three areas were generally low from January through May 1964. But, a slight spring increase in catch occurred in all three areas. This increase could have reflected the entrance into Suisun Bay of young-of-the-year that had remaind upstream and were moving downstream with the increased spring flows.

Off Port Chicago and Martinez, the concentration of 1963 year-class fish, compared to the upstream area, was generally uniform and low.

No 1963 year-class fish were taken in San Pablo Bay until September 1963 (Figure 10). Abundance was high in October, and although de-

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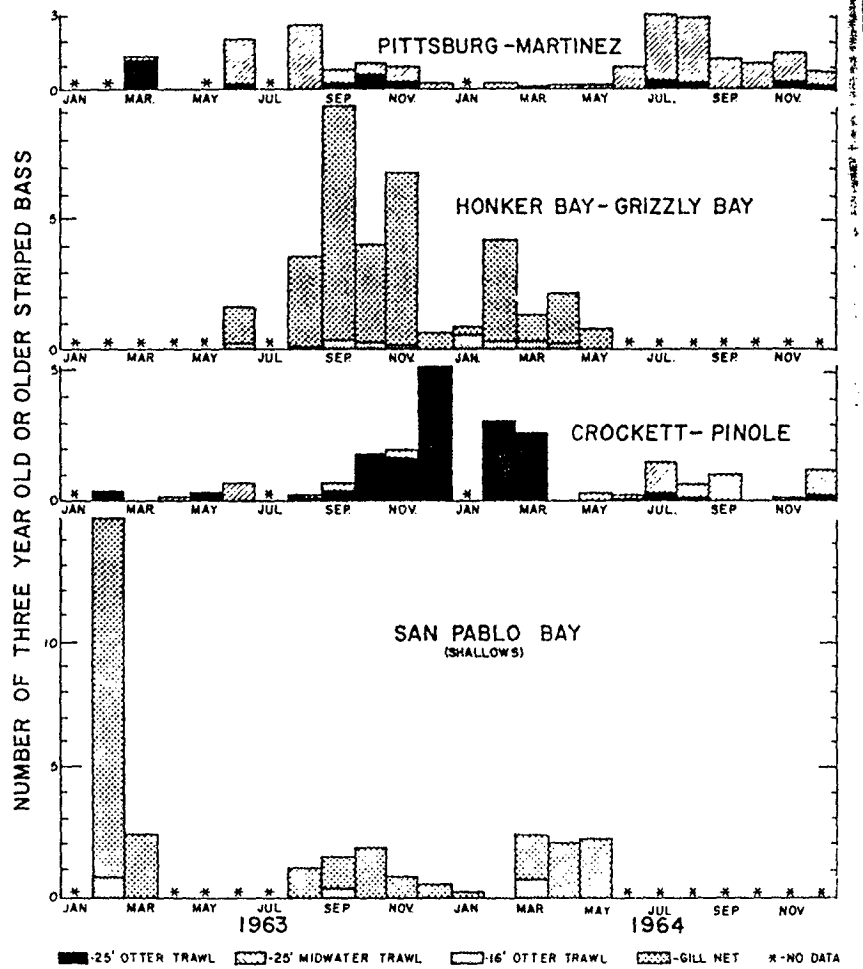

FIGURE 9. Monthly catch of 3-year-old or older striped bass, *Roccus saxatilis*.

clining during November and December, remained relatively high during those months. Young bass were still present in February, March, and April 1964, but were absent in May.

The 1964 year-class started to appear off Pittsburg in June 1964. High abundance was reached in July and from August on the catch fluctuated to a low in December (Figure 10).

At Port Chicago and Martinez, young bass seemed to be present in about the same small quantities as the preceding year.

Few 1964 year-class fish were caught in San Pablo Bay (Figure 10).

At times, the highest catches of young striped bass were made with the 16-foot otter trawl in Honker and Grizzly Bays (Figure 10). The high catches of young-of-the-year fish with this small trawl in the shallows of Suisun Bay led me to believe that such areas are preferred by young bass in their first few months of life.

The migration and distribution of juvenile striped bass (1 to 3 years old) is not well documented. Scofield and Bryant (1926) felt that juveniles as well as young-of-the-year left San Francisco Bay in the winter and spread up and down the coast. Tagging studies by G. H. Clark (1936) did not indicate a migratory pattern, but simply a diffusion from the point of tagging. Calhoun (1949) showed a distribution of 2- to 3-pound bass throughout the Sacramento-San Joaquin system, except for upper and lower San Francisco Bay. Especially heavy catches were made in Suisun Bay during summer and fall.

We took yearling bass during most months in most places where we collected (Figure 11). They were especially concentrated in the Crockett-Pinole area during the winter months. There did not seem to be any particular pattern of distribution in Suisun Bay.

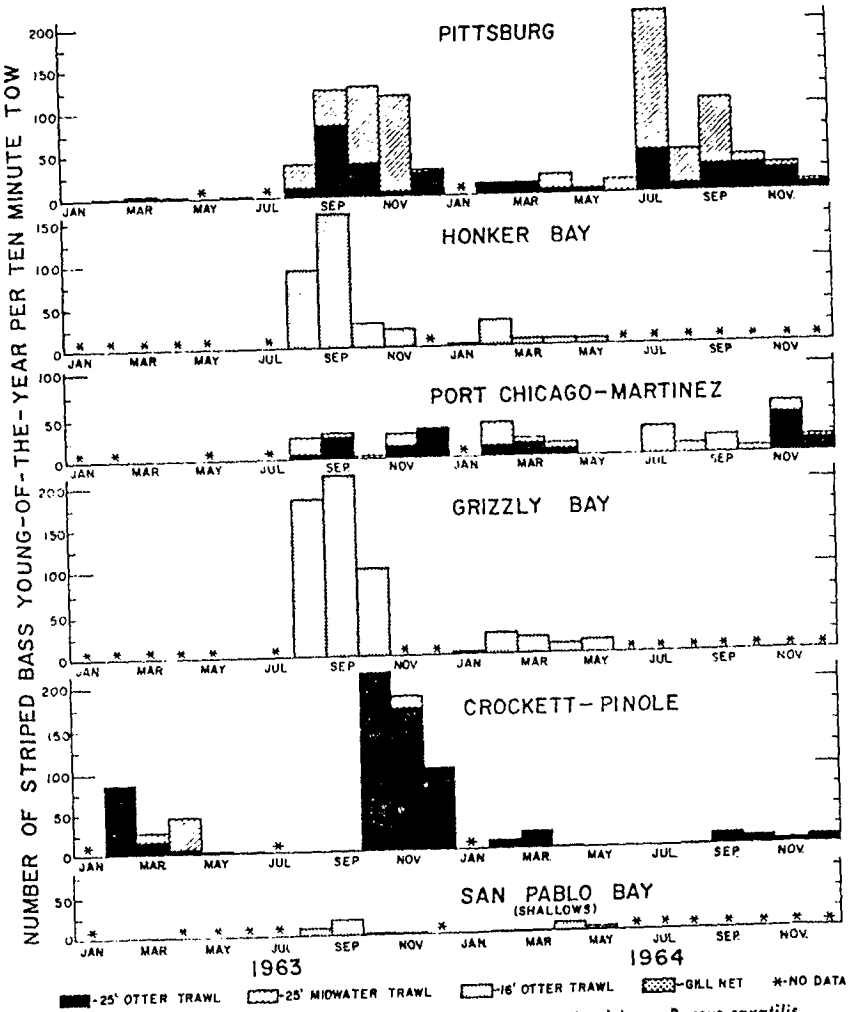

FIGURE 10. Monthly trawl catch of young-of-the-year striped bass, *Roccus saxatilis*.

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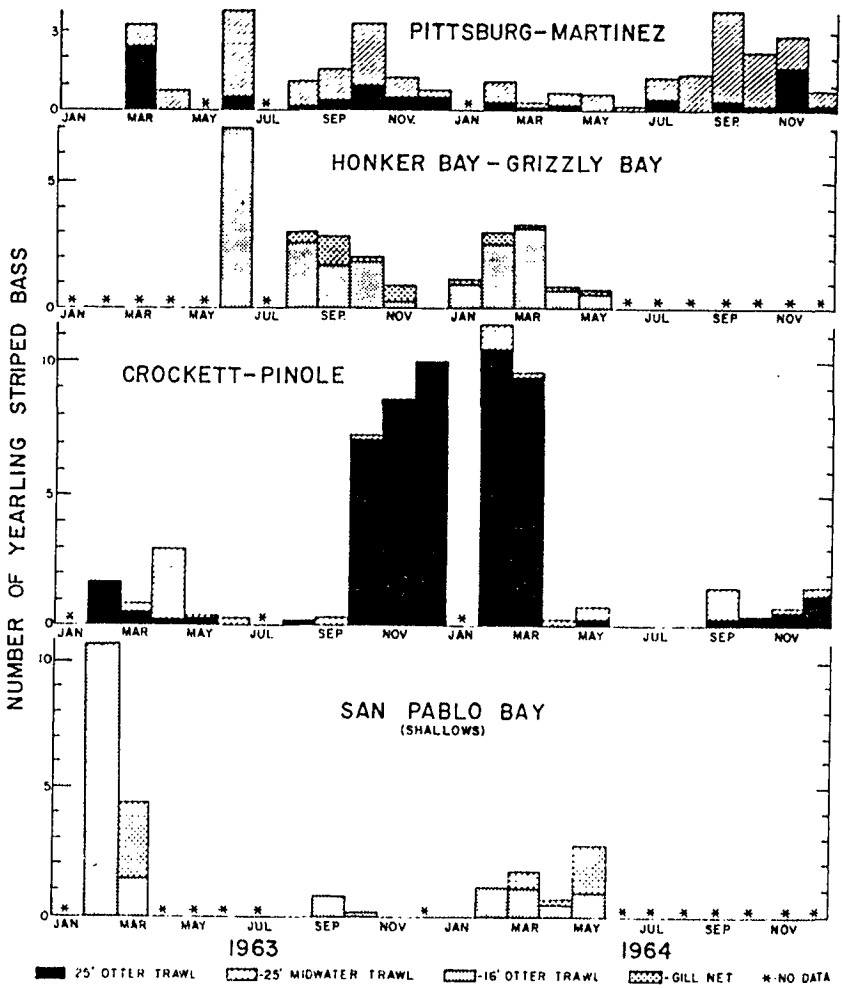

FIGURE 11. Monthly catch of yearling striped bass, *Roccus saxatilis*.

The food habits of striped bass have been investigated on and off throughout the years, but no detailed study has been conducted in Suisun or San Pablo Bays.

E. C. Scofield (1928, 1931) reported on random examinations of stomachs taken throughout the year in San Francisco, San Pablo, and Suisun Bays. He found that striped bass fed on periwinkles and "small crustaceans" when in the flats at high tide and on bay shrimp, anchovy, herring, "smelt," splittail, and their own young when in deeper water. He summed up his observations by saying that practically every marine form common to the San Francisco Bay region had been found in striped bass stomachs.

Hatton (1940) found that the stomachs of 57 young-of-the-year and

tained, in order of the frequency of occurrence, "amphipods," *Synidotea laticauda*, "fish," and *Crago* sp. He found, after the water had freshened considerably, that 100 percent of the identifiable organisms in the stomachs of 45 young-of-the-year bass taken at Martinez in February and March 1940 were *Neomysis awatschensis*. Hatton also examined the stomachs of approximately 100 adult striped bass taken in Suisun Bay between March and May 1939. About 75 percent contained: "unidentified fish," "clupeoids," "osmerids," "split-tails," "lampreys," "atherinids," and "catfish or sculpins." "Shrimp or crab" were found in 25 percent of the stomachs.

Johnson and Calhoun (1952) found that the food of 229 adult and juvenile striped bass, caught during the summer in San Pablo Bay, consisted primarily of bay shrimp and northern anchovy.

Heubach, Toth, and McCready (1963) examined the stomachs of 355 young-of-the-year striped bass caught in the years 1956–1961 between Carquinez Strait and Pittsburg. They found that in the summer, 85 percent contained *Neomysis awatschensis*. Copepods and *Corophium* sp. were present in 19 and 18 percent. In the fall, 77 percent ate *Neomysis awatschensis* and 45 and 19 percent ate copepods and *Corophium* sp.

In the course of our 2-year survey, we examined the stomachs of 739 young-of-the-year striped bass, 602 yearlings, and 492 fish over 2 years of age, that contained identifiable food.

In eastern Suisun Bay, young-of-the-year striped bass fed almost entirely on *Neomysis awatschensis* and *Corophium* sp. (Figure 12). At times, the rate of occurrence of *Corophium* was fairly high but numbers were low and we considered their volumetric contribution to be negligible.

Young-of-the-year bass in middle and western Suisun Bay, although eating *Neomysis awatschensis* and *Corophium* sp. at about the same rate as fish upstream, began feeding on small *Crago franciscorum*, small fish and *Synidotea laticauda* (Figure 12). Unlike *Corophium* sp., these organisms, because of their size, did contribute significantly to the volume of food ingested, but *Neomysis awatschensis* was still dominant.

Neomysis awatschensis became less important in the diet of small bass in San Pablo Bay, and *Corophium* sp. although still present was augmented by its marine counterpart *Photis californica* (Figure 12). Small fish, annelid worms, bay shrimp, and *Synidotea laticauda* began to play an increasingly important role.

In the Pittsburg area, *Neomysis awatschensis* continued to be the predominant food organism utilized by yearling bass, being present in 77 to 100 percent of the stomachs. Small fish, shrimp, and isopods made up the remainder. Yearling bass at Port Chicago, Martinez, and in San Pablo Bay began to depend more on fish, shrimp, and isopods.

Neomysis awatschensis were frequently found in the stomachs of 3-year-old or older bass, but contributed little to the total food consumed. These adults depended almost entirely on *Crago franciscorum* and fish.

The fish diet of the striped bass varied with the size of the individual and the season. The occurrence of a given species of fish in the

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All the common species, including young striped bass and king salmon were utilized at one time or another.

I am indebted to John Thomas, of the Inland Fisheries Branch of the California Department of Fish and Game, who analyzed the stomach contents of most of the large bass during 1964.

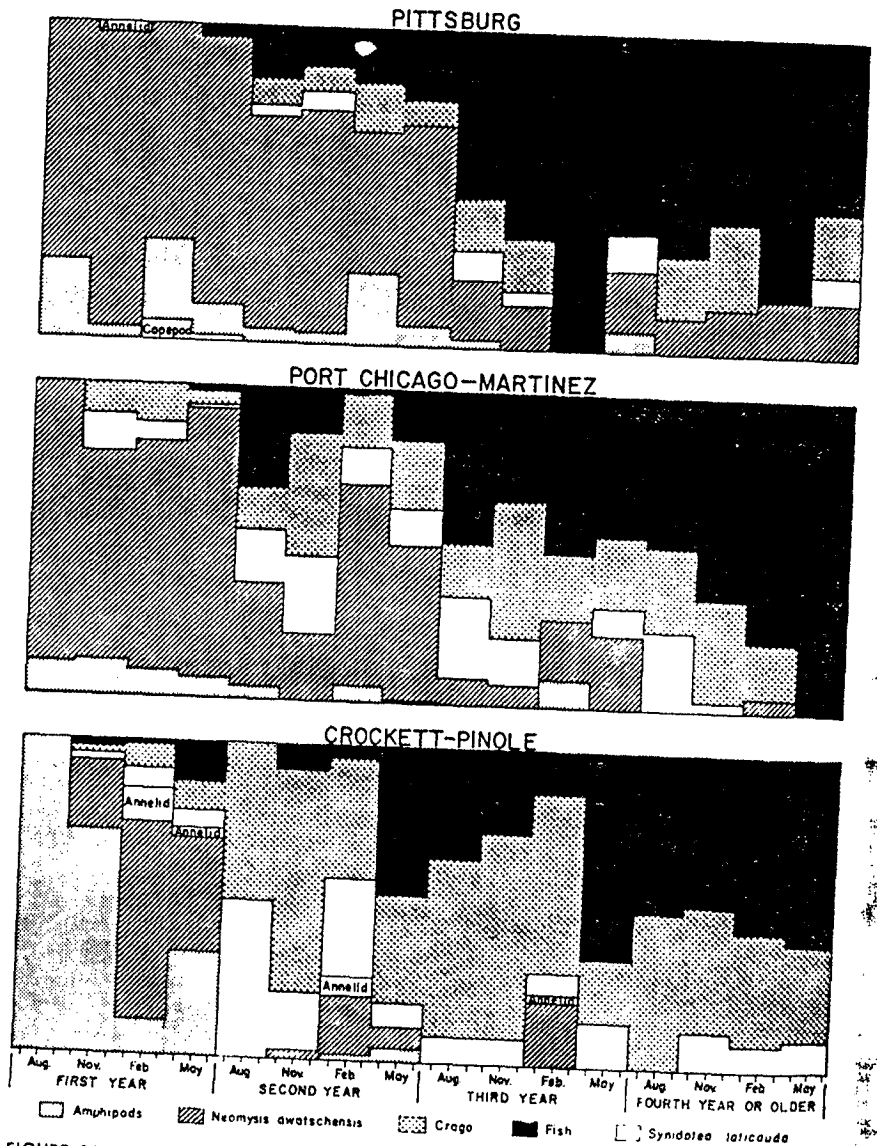

FIGURE 12. Occurrence of various food items in the stomachs of striped bass of different age groups at different seasons in different areas. Columns above months represent 100 percent of all occurrences; i.e., if all of 100 stomachs contained *Crago* and all contained "fish," columnt would show: Crago—50 percent, "fish"—50

Black crappie, *Pomoxis nigromaculatus*. Fresh water. Introduced.

Total—1. Midwater trawl. Martinez: June 1963; 23 cm. Stomach contained one *Neomysis awatschensis*.

Bluegill, *Lepomis macrochirus*. Fresh water. Introduced.

Total—2. Midwater trawl, otter trawl. Pittsburg: February 1963; 4 cm. San Pablo Bay: February 1963; 4 cm.

White croaker, *Genyonemus lineatus*. Marine.

Total—994. Gill net, otter trawl. Martinez, San Pablo Bay.

A few white croakers were caught at Martinez between March and December 1964, but 955 were taken in San Pablo Bay from April to August 1964. Most were 3 to 10 cm long. About 15 fish were 15 to 30 cm long.

Barred surfperch, *Amphisticus argenteus*. Marine.

Total—1. Otter trawl. San Pablo Bay: June 1964; 6 cm.

Black perch, *Embiotoca jacksoni*. Marine.

Total—25. Otter trawl. San Pablo Bay: July 1964; 5 to 7 cm.

Pile perch, *Rhacochilus vacca*. Marine.

Total—33. Otter trawl. San Pablo Bay: June–July 1964; 8 to 33 cm.

Shiner perch, *Cymatogaster aggregata*. Marine.

Total—188. Midwater trawl, otter trawl. San Pablo Bay.

A few shiner perch were caught between February and May 1963, but the majority (177) were taken between May and December 1964. All were from 8 to 14 cm long.

Tule perch, *Hysterocarpus traski*. Fresh water.

Total—2. Midwater trawl, otter trawl. Pittsburg: April 1963; 9 cm. Honker Bay: January 1964; 13 cm.

Walleye surfperch, *Hyperprosopon argenteum*. Marine.

Total—3. Otter trawl. San Pablo Bay: June 1964; 7 to 9 cm.

White seaperch, *Phanerodon furcatus*. Marine.

Total—7. Otter trawl. San Pablo Bay: May–September 1963; 12 to 16 cm. October–December 1964; 27 to 28 cm.

Gobies. Marine—Euryhaline.

Total—72. Midwater trawl, otter trawl.

Although both the arrow goby, *Clevelandia ios*, and the bay goby, *Lepidogobius lepidus* were identified, catches were usually recorded only as "gobies."

Most (61) gobies were caught in San Pablo Bay from May to October 1964. Four were taken off Pittsburg in May and June 1964, and four were caught in San Pablo Bay between May and August 1963. All were 3 to 8 cm long.

Brown rockfish, *Sebastodes auriculatus*. Marine.

Total—41. Otter trawl. San Pablo Bay: June–July 1964; 5 to 7 cm.

Lingcod, *Ophiodon elongatus*. Marine.

Total—31. Midwater trawl, otter trawl. San Pablo Bay: April–July 1964; 8 to 9 cm.

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Prickly sculpin, *Cottus asper*. Fresh water.

Total—2. Otter trawl. Martinez: March and December 1964; 14 and 16 cm.

Staghorn sculpin, *Leptocottus armatus*. Marine—Euryhaline.

Total—2,644. Midwater trawl, otter trawl.

Jones (1962) studied the biology of the staghorn sculpin in Tomales Bay and San Francisco Bay, for 2 years. He concluded that spawning takes place between October and March and that small juveniles are most tolerant of low salinity. Small juveniles migrated into fresh water in spring, were confined to highly saline areas in the summer, and, for the most part, had moved into marine water by autumn.

We caught sculpins in all areas in most months. They reached their greatest abundance in San Pablo Bay in June, July, and August, and at Martinez in the fall. Size ranged from 3 to 22 cm. Small fish, up to 7 cm, were common in the winter and spring, particularly in the flats of San Pablo and western Suisun Bay. Ripe adults 20 cm long were taken in San Pablo Bay in April 1964.

About 85 percent of the sculpins were taken in San Pablo Bay, 13 percent at Martinez or in Grizzly Bay and 2 percent at Pittsburg or in Honker Bay.

Jones (1962) found that the principal food items utilized by 87 adult staghorn sculpins taken in San Francisco Bay were: bay shrimp, the blue mud shrimp, *Upogebia pugettensis*, and the northern anchovy. The principal food organisms eaten by 101 juvenile sculpins in Tomales Bay were: *Corophium spinicorne*, *C. stimpsoni*, and the annelid *Neanthes limnicola*.

In Suisun Bay, we examined two sculpin stomachs with identifiable food. One contained bay shrimp, the other, annelid worms. In San Pablo Bay, three specimens contained bay shrimp.

California pompano, *Palometa simillima*. Marine.

Total—11. Midwater trawl. San Pablo Bay: May 1963, May 1964; 10 to 14 cm.

Atherinids. Marine.

Total—1,292. Gill net, midwater trawl. Martinez, San Pablo Bay.

Both the jacksmelt, *Atherinopsis californiensis*, and the topsmelt, *Atherinops affinis*, were in our catches. When small individuals appeared, it was not practical to separate the two species. However, the presence of ripe and ripening jacksmelt in San Pablo Bay led us to believe that most of the small fish were that species.

The jacksmelt reaches a length of more than 50 cm, matures at the age of about 2 years at a length of about 15 cm, and spawns from October to March (F. N. Clark, 1929; Roedel, 1953).

Over 98 percent of the atherinids we caught were in San Pablo Bay. The remainder, eight adults 20 to 36 cm long, and 10 young, 6 to 9 cm long, were caught off Martinez.

Ripening and ripe adults were found from September to April, but the largest catches were composed of fish between 5 and 12 cm and were recorded from July to December in both 1963 and 1964.

California halibut, *Paralichthys californicus*. Marine.

Total—2. Otter trawl. San Pablo Bay: May 1963; 34 cm. May 1964; 80 cm.

Pacific sandab, *Citharichthys sordidus*. Marine.

Total—50. Otter trawl. San Pablo Bay.

More than 90 percent were caught in June and July 1964. All were between 5 and 11 cm long.

Diamond turbot, *Hypsopsetta guttulata*. Marine.

Total—15. Otter trawl. San Pablo Bay.

In 1963, turbots were caught between August and December. In 1964, from May to December. All were 23 to 42 cm long.

English sole, *Parophrys vetulus*. Marine.

Total—1,050. Otter trawl. San Pablo Bay.

In 1963, only one English sole was caught (December; 24 cm). In 1964, small sole were common during some months. From May through July, 1,000 sole 4 to 10 cm long, were taken and from August through December, 49 between 7 and 18 cm, were caught.

Sand sole, *Psettichthys melanosticus*. Marine.

Total—12. Otter trawl. Martinez, San Pablo Bay.

Two sand sole were caught off Martinez (May, December 1964), 10 in San Pablo Bay (no particular seasonal pattern). Sizes ranged from 5 to 28 cm.

Slender sole, *Lyopsetta exilis*. Marine.

Total—2. Otter trawl. San Pablo Bay: April 1964; 15 and 22 cm.

Starry flounder, *Platichthys stellatus*. Marine—Euryhaline.

Total—about 1,000. Gill net, midwater trawl, otter trawl. San Pablo Bay to Pittsburg.

The starry flounder is found in bays and from very shallow water to about 150 fathoms over all types of bottom but rock. In central California, the fish spawn once a year during winter months. Males mature in their 2nd year when about 30 cm long; females in their 3rd year when about 35 cm long (Orcutt, 1950). The starry flounder is a relatively minor component of the commercial flatfish catch but is an important sport fish in central California (Roedel, 1953).

P. stellatus is known to move far upstream into completely fresh water. It has been taken 75 miles up the Columbia River (Gunter, 1942), and during the fish survey of the Delta in 1963, a small starry flounder was caught at Mossdale on the San Joaquin River. Mossdale is about 90 nautical miles from the Golden Gate and is near the limit of tidal effect. Even in periods of drought, ocean salts are absent there.

We caught about 77 percent of our starry flounders in San Pablo Bay, about 14 percent off Martinez or in Grizzly Bay, and about 9 percent off Port Chicago, Pittsburg, or in Honker Bay.

Although one of the largest (44 cm) fish was caught off Pittsburg, size (and age) generally decreased with distance upstream. Small (4 to 15 cm) flounders comprised about 90 percent of the catch off Pittsburg, Port Chicago and in Honker and Grizzly Bays. Off Martinez, about 50 percent were of that size and in San Pablo Bay 20 to 40 percent. Small fish were most abundant in summer and fall but were scattered throughout the estuary year-round.

Larger (20 to 44 cm) fish were common during most months in San Pablo Bay. An increase in numbers was observed in the spring and

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summer, and the late summer and fall population seemed to be quite high.

In Suisun Bay, we examined 18 stomachs containing identifiable food. Ten had eaten "clam" (mostly *Macoma* sp.), 5 contained *Corophium* sp., 2 *Synidotea laticauda*, and 1 *Neomysis awatschensis*.

In San Pablo Bay, 47 stomachs contained identifiable food: 39 clam (mostly *Macoma* sp.), 8 *Synidotea laticauda*, 4 annelid, 1 *Photis californica*, and 1 unidentified crab.

California tonguefish, *Symphurus atricauda*. Marine.

Total—5. Otter trawl. San Pablo Bay: July, August, October 1964; 9 to 13 cm.

Northern midshipman, *Porichthys notatus*. Marine.

Total—about 700. Midwater trawl, otter trawl. Suisun Bay, San Pablo Bay.

The northern midshipman was most abundant from April to August in both 1963 and 1964. Over 90 percent of the total catch was accounted for during those periods in San Pablo Bay. During the spring and summer months, sizes ranged from 9 to 31 cm, and many of the females contained large, well-developed eggs. From September through the winter months, fish of that size were not common but 3 to 6 cm midshipmen were scattered throughout the bay.

In May and June 1964, three midshipmen were taken near Pittsburg and a few others were scattered throughout Suisun Bay between May and December of both years.

DISCUSSION

The 1962–1963 water year (July to June) was a "wet year" with above-normal precipitation recorded. However, average or below-average rainfall was experienced in the fall and winter and salinity, while steadily decreasing, did not vary widely. In February, March, and April, over 70 percent of the total rainfall was recorded. Heaviest rainfall occurred in February and April, moderate flooding was experienced, and salinity varied abruptly (Figure 13).

The highest average monthly chlorinity recorded at Pittsburg during 1963 was 1‰ in August. For all practical purposes, the water at Pittsburg was fresh during the entire year.

The 1963–1964 water year was a "dry year" with below-normal rainfall recorded. Only in October and November 1963 was above-average precipitation experienced.

At Pittsburg, chlorinity reached 1‰ in May 1964 and a high of more than 3‰ was recorded in August.

Chlorinity at Crockett decreased slowly to 5‰ in January 1964 then slowly rose to a high of 14‰ in August (Figure 13). The fall of 1964 was dry and the chlorinity decreased slowly. The average reading in mid December was between 8 and 9‰. However, 1 week after our survey ended, California was struck by one of the worst storms in its history. On December 22, 1964, the chlorinity at Crockett was 10.7‰; 4 days later the water was completely fresh.

In only 1 of the 24 months of our survey did the average chlorinity at Pittsburg exceed 2.5‰ (Figure 13).

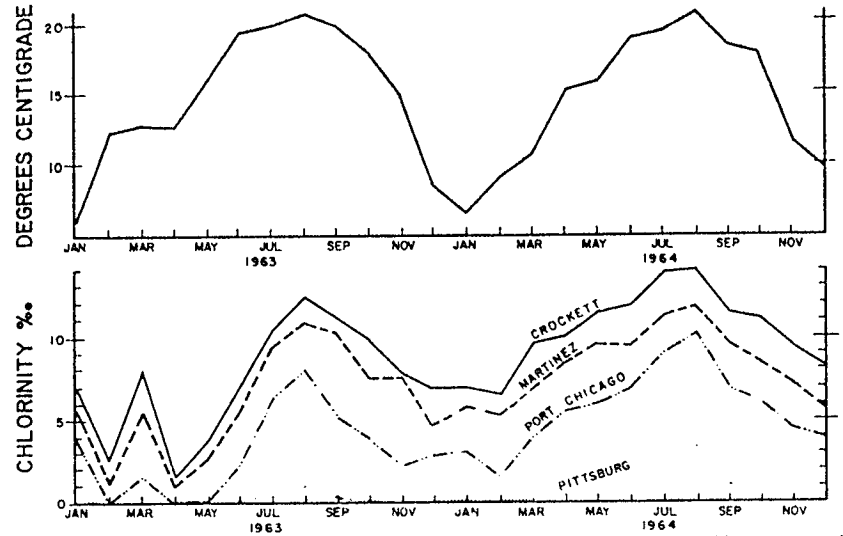

FIGURE 13. Average monthly temperature and chlorinity. Temperature is monthly average of all areas.

for 2 months. At Martinez, chlorinity was 0 to 2.5‰ for 2 months, 2.5 to 9.0‰ for 14 months, and over 9.0‰ for 8 months.

The average monthly chlorinity at Crockett was 9.0‰ or more for 13 months, between 2.5 and 9.0‰ for 9 months and was 2.5‰ or less only during the 2 flood months of February and April 1963.

The estuary is not a static system. The effects of changes (sometimes abrupt) in inflow, two complete tidal cycles of considerable and changing amplitude each day, as well as the effects of wind-driven waves on its large, shallow bays make it a constantly changing dynamic system. Consequently, any classification of an area within the estuary would only be valid for a brief period of time. However, based on the chlorinity readings of 2 years, I feel that it can be divided into three broad zones based on the Venice System of Estuarine Classification (see Kelley, p. 12; Painter, p. 37). They are: an oligohaline or "freshwater" zone centered near Pittsburg, a mesohaline or "brackish" zone centered between Port Chicago and Martinez, and a polyhaline or somewhat less than "marine" zone centered in San Pablo Bay just west of Crockett.

Hedgpeth (1957) stated: "As regions of transition and sharp gradients, estuaries support a fauna recruited principally from the sea, but with a few components from fresh-water environments . . . ."

Of the many species of fish we encountered, most were of marine origin and those decreased in number rapidly or disappeared completely as sampling moved upstream.

Two of the most commonly found so-called euryhaline species of fish, the starry flounder and the staghorn sculpin, though capable of inhabiting waters of a wide salinity range are nevertheless generally

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associated with the marine environment. This is also true of the bay shrimp.

Only 3 of the 13 freshwater species, the carp, the splittail, and the white catfish, were taken with any regularity. The others were rarely caught and in some cases only one was recorded during the entire survey.

Only two species of fish, the Sacramento smelt and the pond smelt, appear to be truly "resident" forms. The Sacramento smelt seems to favor the high end of the salinity gradient, and the pond smelt the low. However, little is known about the life history and behavior of these species in central California, and both warrant further investigation.

Gunter (1945), after a survey of the fish fauna of a Texas estuary, concluded that: ". . . the temperature cycle is chiefly responsible for the seasonal movements and other recurrent cyclic activities of the fishes. In a few instances there were indications that either temperature or salinity was clearly more operative than the other factor in influencing the movements or presence of a species in a given environment at a given time, but mass movements coincide with the temperature cycle. Both salinity and temperature have definite limiting and differential effects which are difficult to separate by observation. . . . During the fall most fishes in the bays began to move toward the Gulf of Mexico. The absence of a species was generally first noticed in the upstream areas. In the spring and summer, the fishes return to the bays."

In our study area, the water temperature (which closely follows air temperature) ranged from 6° C. in January 1963 and 1964 to 21° C. in August of both years (Figure 13). Except for changes caused by flood flows, the salinity increased and decreased in much the same pattern (Figure 13). The general abundance of fish also rose and fell in the same way.

It was not possible to separate the effects of temperature and salinity on the obvious seasonal migrations and changes in abundance of such species as the king salmon, American shad, jacksmelt, striped bass, Sacramento smelt, Pacific herring, and northern anchovy, but the general agreement between my data from Crockett and Martinez and those presented by Messersmith (see p. 57) indicates that the seasonal changes in the concentrations of those species are consistent and predictable. However, the effect of salinity on the degree of penetration into the estuary of some of the marine and marine-euryhaline species can be demonstrated.

The average chlorinity at Crockett for the 6-month period from January through June 1963 was 5‰ and for the first 6 months of 1964, 9‰. At Port Chicago, chlorinity was 1.1‰ from January through June 1963 and 4.5‰ in 1964. This means that the estuary was not subjected to abrupt and violent changes in outflow and salinity in the winter and spring of 1964 as it was in 1963, and that a given isohaline was obviously more stable in position and occurred several miles farther upstream in 1964.

In "dry" 1964, the northern anchovy and Pacific herring moved farther up the estuary and the center of abundance of young Sacramento smelt shifted from San Pablo Bay in 1963 to Suisun Bay in 1964.

Small bay shrimp appeared in Suisun Bay earlier and in greater numbers, and market crabs, almost totally absent in 1963, were common in San Pablo Bay and present at Martinez.

Several marine forms were caught in San Pablo Bay only in 1964, and some that were not numerous in 1963 were common in 1964.

Since there was no real difference in seasonal temperature between the 2 years, it would seem that variations in outflow and salinity were the dominant factors controlling longitudinal distribution of animals within the estuary.

In the future, with increased upstream development and control of water, extremes of flow will be reduced. Such conditions would allow the transient and seasonal marine and anadromous populations to enter and leave the estuary without being subjected to as many violent and sometimes lethal chemical and physical changes, such as probably occurred in the spring of 1963 and in the winter (after our survey ended) of 1964. Such conditions would probably favor the establishment of more stable and permanent estuarine populations.

SUMMARY

From January 1963 to December 1964, a 25-mile section of the Sacramento-San Joaquin River estuary, from the confluence of the two rivers to San Pablo Bay, was regularly sampled with trawls and gill nets. We were particularly interested in determining the distribution, general abundance, and food habits of the fishes within the salinity gradient.

Sixty species of fish were recorded. Of these, 31 were saltwater forms, 8 were euryhaline, 13 were freshwater species, and 8 were anadromous. Freshwater species were generally few in number and restricted to the upper end of the survey area. Marine forms were generally restricted to the lower end. The abundance of several marine species fluctuated widely with season.

The middle portion of the survey area was characterized by the presence of anadromous and euryhaline species and seasonal immigrations and emigrations of marine and freshwater forms. There appeared to be few resident species.

Ocean salt moved farther upstream during the 2nd year (1964) of the survey and the number of marine species increased. Some species taken in both years moved upstream earlier and farther in 1964 than in 1963.

Bay shrimp, *Crago* spp., were common during the summer and fall, and were important in the diets of large striped bass. Bay shrimp were more heavily concentrated in Suisun Bay and were abundant farther up the estuary in 1964 than in 1963.

Pacific herring, *Clupea pallasi*, entered the estuary each year. They produced millions of young which were abundant in San Pablo Bay during May and June of 1963 and upstream throughout Suisun Bay during April and May of 1964. Except for this short time in the spring, herring were rare in, or absent from, our catches.

The northern anchovy, *Engraulis mordax*, entered the estuary in large numbers during the spring and summer. All sizes from 17 cm

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them farther upstream in 1964, and they were more abundant in San Pablo Bay that year.

Young-of-the-year striped bass moved downstream from the Delta and were particularly abundant throughout Suisun Bay from August through November of both years. They were abundant in San Pablo Bay in October, November, and December of 1963 but were scarce there in 1964. Our high catches of young-of-the-year bass with relatively inefficient trawling gear in the "flats" of Suisun Bay suggest that these areas are probably of great importance to the young bass.

King salmon, *Oncorhynchus tshawytscha*, young-of-the-year were most abundant during their downstream migrations in April, May, and November.

Adult American shad were most common in our catches in the spring, during their upstream spawning migration. Some young-of-the-year and yearling shad were always present in the estuary but the numbers of these were greatest in the fall. Eleven adults with "spent" gonads were caught in September 1963, suggesting that some adult shad spawn and return to the sea.

The pond smelt, *Hypomesus transpacificus*, was restricted to the low end of the salinity gradient.

The Sacramento smelt, *Spirinchus thaleichthys*, was found throughout the estuary and seemed to move upstream with increased salinity. Young Sacramento smelt were abundant in April and May.

The food habits of several fishes were investigated, and although many organisms were utilized, the opossum shrimp, *Neomysis awatschensis*, formed an important and probably critical link in their food chain. Striped bass in their 1st and 2nd year of life fed intensively on *Neomysis awatschensis*. Older bass ate a variety of small fish and shrimp. The composition of their food varied with season and location within the estuary. American shad of all sizes fed almost entirely on copepods and opossum shrimp.

Most of the fishes and shrimp that inhabit the Suisun-San Pablo Bay section of this estuary migrate up or downstream as they grow and as the seasons change. The pattern of migration was similar during the two seasons studied but the extent of movement—especially that of marine forms upstream—was different. This is probably because of different salinity conditions during the 2 years.

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SEASONAL DISTRIBUTION OF CRUSTACEAN PLANKTERS IN THE SACRAMENTO-SAN JOAQUIN DELTA

JERRY L. TURNER

INTRODUCTION

Zooplankton collections in the Delta were made over a 12-month
riod from March 1963 to February 1964. This report describes
standing crop of crustacean plankters and some of the physical
chemical factors that affect their distribution and abundance.

Seasonal variation in concentration of crustacean plankters was
related with seasonal variation in water temperature. "Resid
time" of water in a channel was an important factor influencing
dance in channels containing water of the same river system. D
ences in dissolved solids appeared to be the major cause of differ
in the zooplankton abundance of the different river systems withi
Delta.

Field Methods

Zooplankton samples were collected once a month from 20 Del
tions which had contrasting conditions of flow, water quality, an
perature.

Collections were made with a Clarke-Bumpus sampler fitted
number 10 net (109 meshes to the linear inch). Ricker (1938)
strated that a number 10 net sampled adult crustaceans in pro
to their abundance.

The sampler was towed near the surface behind a power boat
at approximately 3 feet per second relative to the current s
10 to 15 minutes. The sampler metered the volume of water
through the net. Samples were usually collected from station
San Joaquin River and south Delta on one day and from th
mento River and Mokelumne River region of the Delta on the
day. They were preserved with formalin. Rose bengal dye w
to facilitate visual separation of animals from detritus.

At the time of sampling, the surface water temperature was
and a sample of water was collected so that its electrical co
could be measured. Measurements were made with an AC w
bridge and were used to help distinguish the origin of wat

The Department of Water Resources provided estimates of
flows and cross-sectional areas of the channel at each statio
samples were collected. These estimates were based upon t
measurements of inflow to the Delta and past studies of th
ships between these inflows and the net flows and cross-sect
of the separate Delta channels (Calif. Dept. Water Resour
They were used to compute "mean net velocities"

$$\frac{\text{mean net flow in cubic feet/second}}{\text{area of cross section of channel in square feet}}$$

of the time a given amount of water remains i

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